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AUSTENITIC ELECTRODES FOR UNDERWATER WET WELDING.(U)
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CIVIL ENGINEERING LABORATORY
Naval Construction Battalion Center
Port Hueneme, California

Sponsored by
NAVAL FACILITIES ENGINEERING COMMAND

AUSTENITIC ELECTRODES FOR UNDERWATER WET WELDING

June 1977

An Investigation Conducted by

THE INTERNATIONAL NICKEL COMPANY, INC.
New York, New York

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Twelve austenitic electrodes were evaluated for use as wet welding electrodes. The type electrodes investigated were: Inco-Weld A and two modifications, INCONEL Welding Electrodes 112 and 182 and a semi-commercial stainless electrode designated R-142 and five modifications. E6013 was used as a standard. The welds were bead-on-plate and three bead multipass deposits. Most welds

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were made automatically in 3-1/2% NaCl solution with gravity fed electrodes and controlled travel speed. Direct current, straight polarity and the drag technique were used.

The evaluation was based on operability, porosity, crack resistance and undercut. The factors considered for operability were bead appearance, slag removal, arc stability and ease of operation. The effect of travel speed, current and coating thickness on bead appearance and porosity were determined. The coating thickness was also related to depth of cup.

Ten pounds each of 0.190 and 0.220 inch coating diameter R-142 and 0.190 inch coating diameter INCONEL Welding Electrode 112 were shipped to the Civil Engineering Laboratory, Naval Construction Battalion Center at Port Hueneme, CA, for further evaluation.

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AUSTENITIC ELECTRODES FOR UNDERWATER WET WELDING

1.0 ABSTRACT

Twelve austenitic electrodes were evaluated for use as wet welding electrodes. The type electrodes investigated were: Inco-Weld A and two modifications, INCONEL Welding Electrodes 112 and 182 and a semi-commercial stainless electrode designated R-142 and five modifications. E6013 was used as a standard. The welds were bead-on-plate and three bead multipass deposits. Most welds were made automatically in 3-1/2% NaCl solution with gravity fed electrodes and controlled travel speed. Direct current, straight polarity and the drag technique were used.

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2.0 INTRODUCTION

U.S. Navy requirements have historically involved salvage operations. Welds have been used to temporarily join pad eyes and patches to recoverable objects. Navy needs, however, are expanding to include the capability to make long-term structural quality underwater welds. Examples of these requirements are underwater maintenance and repair of ocean founded towers and underwater preparation of ship hulls for mothballing. The primary objective of this electrode investigation is to determine the feasibility of improving weld quality by development and evaluation of austenitic electrodes for wet welding SAE 1020 steel. The Paul D. Merica Research Laboratory was to investigate electrodes and make recommendations for further testing by the Civil Engineering Laboratory at the Naval Construction Battalion Center in Port Hueneme, CA. Three commercially available nickel-base electrodes and a semi-commercial stainless steel electrode were selected for investigation. A secondary objective of this investigation was to make observations which may be pertinent to future work.

3.0 RECOMMENDATIONS

One-eight inch diameter core wire INCONEL Welding Electrode 112 with a 0.190 inch diameter coating and R-142 with 0.190 and 0.220 inch diameter coating are recommended for further testing. The recommended welding parameters for underwater wet welding are: INCONEL Welding Electrode 112 - 110-140 amperes, 32-38 volts; R-142 - 0.190 inch coating - 120-150 amperes, 34-38 volts; 0.220 inch coating - 130-150 amperes, 36-42 volts.

4.0 OBSERVATIONS

1. Bead appearance was improved and porosity was increased with increasing current for a given electrode.

2. The welds made with the austenitic electrodes were free of undercut, weld and underbead cracking.

3. The optimum thickness of coating varied with each electrode.

4. The depth of cup increased with coating thickness.

5. Proper waterproofing is necessary for satisfactory operation of the electrodes underwater.

6. Excessive heating of the electrode during welding resulted in shriveling and loss of adherence of the waterproof coating.

7. The waterproofing was not burned completely by the arc.

5.0 EXPERIMENTAL PROCEDURE AND MATERIALS

5.1 Underwater Welding Fixture

Initially, welding was attempted manually. It was soon apparent that welding would have to be done automatically for more reproducible results and in order that results could be quantitied. Visibility was a major problem. The first fixture (Figure 1) worked well in air but not in water. A second fixture (Figure 2) was designed and was used throughout the program with minor modifications. The procedure used in making welds with this fixture is described below.

The fixture was attached to an automatic travel carriage. The base plate was stationary and held down in place. The fixture was totally immersed in a 16" high x 24" long x 14" wide stainless steel tank during welding (Figure 3). The electrode was at a 20 degree angle to the line of the weld. The electrode was lowered to make contact with

the base plate, raised slightly, and then the current was turned on to start the arc. The electrode was then dropped on the base plate for drag technique welding. The switch for controlled travel speed was turned on and the electrode was allowed to burn completely before turning off the power. The electrode was lowered by gravity and its rate of fall was controlled by the use of counterweights. The dead weight of the electrode and holder was 1 pound in salt water except in those tests where it was varied on purpose.

The electrode was held slightly above the base plate to start the arc since we did not have a knife switch arrangement in the electrical system. Otherwise, the electrode would stick to the base plate if the current was turned on with the electrode in contact with the base plate.

5.2 Welding Media

Most welds were made in a solution consisting of 3-1/2% NaCl (by weight) in demineralized water. The NaCl was a technically pure or all-purpose NaCl and not a chemically pure grade. Tap water was found to cloud very badly when NaCl was added providing very poor visibility whereas, demineralized water remained clear before initiation of welding. The water discolored badly after making a few welds and had to be changed often. Several welds were made in demineralized water without NaCl added.

5.3 Welding Equipment

Our power source was a Westinghouse rectifier with a capacity of 500 amperes. The electrode holder for most welds was ARCAIR Model 14-050-121. The holder was adapted for use with 1/8 inch diameter electrodes.

5.4 Materials

5.4.1 Base Metal. The composition of the base metal, SAE 1020 steel, is given in Table I. Carbon equivalent was 0.28% based upon the formula:

$$CE = \%C + \frac{\%Mn}{6} + \frac{\%Cr + \%Mo + \%V}{5} + \frac{\%Ni + \%Cu}{15}$$

The plate was welded in the hot rolled condition. Plate size for welding was 1/2" x 6" x 12".

5.4.2 Welding Electrodes. Thirteen different type electrodes were investigated. These were nickel-base, stainless, and E6013 which was our standard. The nickel-base electrodes were: Inco-Weld A, two modifications of Inco-Weld A and INCONEL Welding Electrodes 112 and 182. The stainless steel electrodes were a PDMRL semi-commercial electrode designated R-142 and 5 modifications of it.

The compositions of undiluted deposits made in air with R-142 and the nickel-base electrodes are given in Table I.

The tensile strengths of undiluted weld metal deposited in air from these electrodes are in the range of 80 to 110 ksi (Table II).

5.4.2.1 Core Wire. The compositions of the core wires used for the R-142 electrode and its modifications are given in Table III. All compositions listed are within the melting range of R-142 core wire. The diameter of the core wire of all electrodes was 1/8 inch. The stainless and modified Inco-Weld A core wires were 14 inches long whereas, the remaining core wires were 12 inches long.

5.4.2.2 Fluxes. The compositions of the fluxes investigated with the R-142 core wire are also given in Table III. Fluxes 1 and 2 are the standard R-142 flux. The modifications tried were: variations in MnO_2 content (fluxes 3 and 4), substitution of $MnCO_3$ for MnO_2 (flux 6) and substitution of $MnCO_3$ for MnO_2, omission of FeCb and a change in binder of K_2SiO_3 for Na_2SiO_3 (fluxes 5 and 7). The fluxes used for the nickel-base electrodes are proprietary to Huntington Alloys, Inc.

Three coating thicknesses were investigated on the more promising electrodes which were R-142, R-142A (12%MnO_2 instead of 18%MnO_2) and INCONEL Welding Electrode 112. The flux coating outside diameters were 0.190, 0.220 and 0.250 inch. The coatings were extruded onto the core wire with an Oerlikon extruder. The electrodes made at PDMRL were baked 3 hours at 550°F after extrusion.

5.5 Welding Parameters

All welds were made downhand using the drag technique. Direct current and straight polarity were used on most welds. Reverse polarity was used in preliminary work in evaluating the automatic equipment and two other welds. Straight polarity is recommended for underwater welding since reverse polarity results in accelerated corrosion of the electrode holder.

The effects of welding speed (6-10 ipm) and current (110-170 amperes) on bead appearance and porosity were established on the nickel-base and stainless electrodes. All welds made with the E6013 electrode were at 8 inches per minute with 160-165 amperes and 27-28 volts.

All preliminary evaluation was with single bead-on-plate tests. Final evaluation included multipass welds

(3 beads) in grooved plate. The grooves were 1/8 inch deep, 1/8 inch wide at the top with a 45 degree sidewall and 3/32 inch deep, 1/4 inch wide at the top with a 35 degree sidewall. The first bead was deposited in the center of the groove and the second and third beads were offset 1/8 inch from the center on each side of the first bead. The multipass welds were made to establish how well the electrodes could be deposited on their own deposits and diluted weld metal. The deeper groove was also considered to be a measure of welding in a difficult to reach area.

5.6 Waterproofing

The electrodes were waterproofed by dipping in a solution containing 0.5 pound cellulose nitrate per gallon. The lacquer as purchased from Pearl Paint Company, NY, NY contained 2.5 pounds cellulose nitrate per gallon. This was mixed with acetone to give the desired concentration. Two dips were used. The electrode was held in the solution for 20 seconds to insure good coverage and dried for an hour between dips.

The waterproofing was removed from the contact points of the electrode by belt sanding before welding. This was done at the point of contact for starting of the electrode and also the uncoated portion of the electrode which went into the electrode holder.

6.0 EVALUATION

Welds were evaluated for operability, porosity cracking and undercutting.

6.1 Operability

Operability was based upon bead appearance, slag removal, arc stability and ease of operation.

6.1.1 Bead Appearance. Bead appearance was rated very good (VG), good (G), fair (F), poor (P) or very poor (VP). These are qualitative ratings based upon the judgement of the welder. The desired appearance was a bead of uniform width which was neither too convex nor concave.

6.1.2 Slag Removal. Slag removal was judged as good when the slag was removed completely by scraping a chisel along the surface of the weld bead underwater.

6.1.3 Arc Stability. Arc stability was based upon the ability of the electrode to burn completely without interruption and if interrupted, to be re-ignited readily.

6.1.4 Ease of Operation. The two variables which are controlled by the welder in manual welding were considered under ease of operation. These are the downward force applied to the electrode and travel speed. The questions to be answered were: (1) "Did the electrode require a soft touch for proper operation?" and (2) "How did changes in travel speed affect bead appearance and/or porosity?". A measure of "softness of touch" was obtained by changing the freely falling weight of the electrode holder such that the downward force on the electrode was 1, 1-1/2 or 2 pounds in salt water. This was accomplished by the use of counterweights in the system. The change in dead weight on the electrode also established whether the flux coating was strong enough to maintain a cup when a "heavy touch" was applied with the drag technique. The changes in welding speed were described previously under welding parameters (Section 5.5).

6.2 Porosity

The porosity of the welds was determined by x-ray radiography and calculated as cross sectional area. Porosity was rated as coarse, medium or fine based upon a reference chart for welds in unfired pressure vessels, Section VIII (Figure 4). The average diameters given for coarse, medium and fine pores in 1/2 inch thick welds in the above specification are 0.010, 0.031 and 0.0195 inch, respectively.

6.3 Cracking and Undercut

All welds were examined at 10X magnification for surface cracking. Selected welds were sectioned, polished, etched and examined for underbead cracking at a magnification of 10X. All welds were examined for undercut.

7.0 RESULTS AND DISCUSSION

Table IV lists all welds made, the purpose of test, welding parameters, bead appearance, a description of the porosity observed, calculated cross sectional area of the porosity and remarks.

Photographs of all welds are given in Figures 5 through 18. The effect of coating diameter on depth of cup is depicted in Figure 19 (R-142) and Figure 20 (R-142A - 12%MnO_2 instead of 18%MnO_2). Figure 21 shows the deepest cup which was found in all tests (0.250 inch diameter coating INCONEL Welding Electrode 112) and our standard, E6013. A discussion of various facets of the investigation follows.

7.1 Reverse vs. Straight Polarity

Welds 1 and 2 were made with reverse polarity and 3 and 4 with straight polarity (Figure 5) in fresh water. These were the first welds made with straight polarity with the electrode fully immersed in water and demonstrated that a nickel-base electrode could be deposited using straight polarity. Nickel-base electrodes are generally designed for welding with reverse polarity.

7.2 Design of Fixture for Automatic Welding

The welds coded 5 through 14 (Figure 6) were made with the first fixture and established that the difficulties encountered in making these welds were associated with the loss of power through the metal supports underwater and the power connection to the electrode. Neither Glyptal nor Permatex, which were used as insulation material, withstood the salt water environment for any length of time. These tests as well as others not listed led to using non-conducting materials of construction (Micarta and Teflon) throughout the system in the second fixture and also led to the purchase of a fully insulated electrode holder designed for underwater welding.

The six welds listed as A through F in Table IV were made with the second fixture and showed that the fixture worked well. Some minor modifications were made up through weld 43. One modification was the use of Teflon inserts for guidance of the electrode. An insert with a hole .020 inch in diameter greater than the coating diameter was most effective in preventing hang-up or whipping.

7.3 Operability

The electrodes were rated in the following order: R-142, INCONEL Welding Electrode 112, Inco-Weld A and INCONEL Welding Electrode 182. The results which led to the above rating are described below.

7.3.1 Arc Stability. All electrodes burned well. The most consistent was R-142. The most difficult to start was INCONEL Welding Electrode 182.

The discontinuities observed in some of the weld deposits were not necessarily related to poor arc stability of the electrodes. Sometimes, the electrode hung up in the fixture because of debris and the arc went out as the travel carriage continued to operate. Once the electrode was freed and the arc re-ignited welding continued normally.

7.3.2 Slag Removal. The electrodes had good slag removal except for Inco-Weld A. This electrode was considered unsatisfactory because fragments of slag which were

very adherent remained on the surface after cleaning, particularly near the fusion line. This could prove to be a problem in multipass welds.

7.3.3 Ease of Operation. The effects on bead appearance and porosity of the two variables controlled by the welder are given in Tables V and VI and summarized below.

7.3.3.1 Downward Force on Electrode. The electrodes were rated in the following order for bead appearance in relation to changes in downward force applied on the electrode: Inco-Weld A, R-142, INCONEL Welding Electrode 112 and INCONEL Welding Electrode 182. The latter was considered to have an unsatisfactory performance in this test.

The change in downward force did not have a consistent effect on porosity. All the welds had an acceptable level of porosity.

7.3.3.2 Travel Speed. The effect of travel speed on bead appearance varied with the electrode type (Table VI). R-142 gave acceptable bead appearance at 8 and 10 ipm but not at 6 ipm. Deposits of INCONEL Welding Electrode 182 had poor bead appearance at 6 and 8 ipm but improved at 10 ipm. The bead appearance of Inco-Weld A deposits decreased in rating with increased travel speed and was unsatisfactory at 10 ipm. INCONEL Welding Electrode 112 had an acceptable bead appearance at all travel speeds.

Travel speed did not have a uniform effect on porosity although in three of four cases porosity decreased with increased travel speed. All of the welds in the series had acceptable porosity levels.

7.4 Manual Welding

Manual welds were made with the new electrode holder (Figure 9). The ratings (Table IV) improved as the welder became more proficient however, more expertise would be required to produce satisfactory welds repeatedly. Much of the problem was due to poor visibility. Inco-Weld A was rated good in bead appearance but had very poor slag removal.

7.5 Summary at This Stage

R-142 and INCONEL Welding Electrode 112 showed promise and work was continued on these electrodes. Since Inco-Weld A had satisfactory overall performance except for slag removal variations of the flux were tried to improve the slag removal. Modifications of the R-142 flux were tried also. INCONEL Welding Electrode 182 was dropped from further consideration.

Ten electrodes of R-142 and INCONEL Welding Electrode 112 were shipped to CEL for testing. Satisfactory results were obtained by CEL on INCONEL Welding Electrode 112 in 10 feet of water. The R-142 electrode was not tested at CEL.

7.6 Flux Modifications

The 12% MnO_2 version of the R-142 flux designated R-142A and substitution of 18% $MnCO_3$ for MnO_2 in the R-142 flux gave acceptable operability, however, the $MnCO_3$ substitution resulted in a slight increase in porosity (flux 6 in Table III, Weld 54). All other changes in the flux composition of R-142 (Table VII, Figures 10 and 11) resulted in poor bead appearance or excessive porosity.

The two modifications of Inco-Weld A had improved slag removal (welds 46 and 95) over the commercial Inco-Weld A, but still were not considered satisfactory.

7.7 Effect of Current

Increased current generally resulted in improved bead appearance and/or increased porosity for the R-142 and R-142A electrodes (Table VIII). A current maximum of 150 amperes appears reasonable for these electrodes.

7.8 Coating Thickness Effects

The thickness of the coating affected both the operability and depth of cup. The optimum coating thickness varied for each type electrode. INCONEL Welding Electrode 112 had the best operability with a 0.190 inch diameter coating, whereas R-142 and R-142A had good operability with the 0.190 and 0.220 inch diameter coatings (Tables VIII and IX, Figures 12-18). The 0.220 inch diameter coating had a slight advantage in the grooved multipass welds.

The depth of cup increased with increasing coating thickness. This occurred with all electrodes and is shown in Figures 19 (R-142) and 20 (R-142A). Figure 21 shows the depth of cup obtained with the E6013 electrode. The deepest cup found in all tests was on a 0.250 inch diameter coated INCONEL Welding Electrode 112 (Figure 21). Higher voltages were obtained with the thicker coatings (Table IX) and is probably related to the longer arc length because of the deeper cup.

A long piece of waterproofing compound is still attached to one of the stubs shown in Figure 21. This was not unusual and found on many electrodes. Apparently, the waterproof coating was not burned completely by the arc.

7.9 Cracking and Undercut

Cracking (including underbead) was not observed in any of the welds made. Examples of the cross sections of some of the welds are given in Figure 22.

Undercutting was not observed in any of the welds made with the austenitic electrodes. The welds made with the E6013 electrode did have undercutting.

8.0 FUTURE WORK

Ten pounds of each of the above electrodes were shipped to CEL for further evaluation. Bead-on-plate, fillet and restrained and unrestrained butt joints will be made by Chicago Bridge and Iron and evaluated for mechanical properties by CEL. The work at PDMRL is complete under the present contract.

9.0 ACKNOWLEDGEMENT

Helpful discussions from a welder's standpoint were held with L.R. Meisch throughout this work. Mr. Meisch made all the welds of this investigation.

E.P. Sadowski
E.P. Sadowski
Project Manager

TABLE I

COMPOSITIONS OF DEPOSITS MADE IN AIR AND BASE PLATE

Type	Ni	C	Mn	Fe	S	Si	Cu	Cr	Cb	Mo	Ti	V
Inco-Weld A	70	.03	2.0	9.0	.008	.30	.06	15.0	2.0	1.5	--	--
INCONEL Welding Electrode 112	61	.05	0.30	4.0	.010	.40	--	21.5	3.65	9.0	--	--
INCONEL Welding Electrode 182	67	.05	7.75	7.5	.008	.50	.10	14.0	1.75	--	.40	--
R-142[a] (Semi-Commercial)	24.8	.065	1.24	Bal.	.010	.27	--	18.9	2.24	6.6	--	--
1020	<.03	.20	.47	Bal.	.026	.009	.01	.02	--	.01	--	<.002

(a) Average of 3 deposits - others are nominal.

TABLE II

PROPERTIES OF DEPOSITS AS-WELDED IN AIR

Type	0.2% Y.S. (ksi)	U.T.S. (ksi)	% Elong.	% R.A.
Inco-Weld A	40[a]	80	30	--
INCONEL Welding Electrode 112	60[a]	110	30	--
INCONEL Welding Electrode 182	45[a]	80	30	--
R-142	67	98	23	27

(a) Minimum - all-weld-metal specimens - Source - Publication - Joining Huntington Alloys - Published by Inco, Inc.

TABLE III

CORE WIRE AND FLUX COMPOSITIONS

Core Wire

Code	C	Si	Ni	Cr	Mo	Mn	P	S	Al	Ti
A	.027	.56	24.2	20.3	6.4	1.42	.023	.004	.04	--
B	.010	.98	24.2	19.8	6.2	1.79	.015	.004	.052	.037
C	.043	.31	24.1	20.2	6.5	.96	.003	.013	<.01	<.01
D	.012	.50	26.0	20.3	7.1	.31	.004	.005	<.01	<.01
E	.059	.10	26.1	21.7	6.7	.05	.002	.004	.15	.07

Flux[a]

Code	$CaCO_3$	$NaAl_3F_6$	TiO_2	$MnCO_3$	MnO_2	$Fe_{60}Cb$	Na_2SiO_3[b]	K_2SiO_3
1[c]	25	18	18	--	18	18	15	--
2[d]	25	18	18	--	18	18	15	--
3	28	21	18	--	12	18	15	--
4	29	22	20	--	8	18	15	--
5	30	22	23	22	--	--	15	--
6	25	18	18	18	--	18	15	--
7	30	22	23	22	--	--	--	15

[a] All fluxes contain 3% bentonite.
[b] 15 Na_2SiO_3 and K_2SiO_3 added to dried weight of other ingredients.
[c] Produced commercially.
[d] Produced at PDMRL.

NOTE: Electrodes sent to CEL consisted of:

Core Wire A + Flux 1 - .190" diameter coating, R-142.
Core Wire B + Flux 2 - .220" diameter coating, R-142.

TABLE IV

WELDING PARAMETERS, PURPOSE OF WELD, POROSITY, BEAD APPEARANCE

First Automatic Rig

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
1	Bead-on-Plate	E6013	.196	Fresh Water, Reverse Pol.			F	--	Undercut
2	Bead-on-Plate	INCONEL WE 182	.190	Fresh Water, Reverse Pol.			F	--	Difficult to Start Arc
3	Bead-on-Plate	E6013	.196	Fresh Water, Straight Pol.			F	--	Bead Not as Wide as 1
4	Bead-on-Plate	INCONEL WE 182	.190	Fresh Water, Straight Pol.			F	--	--
5	Bead-on-Plate	E6013	.196	Salt Water	160	23	G	--	Undercut
6	Bead-on-Plate	INCONEL WE 182	.190	Salt Water	130	27	F	--	--
7	Bead-on-Plate	INCONEL WE 182	.190	Salt Water	140	--	--	--	Difficult to Start Arc
8	Bead-on-Plate	R-142	.190	Salt Water	130	27	F	--	Arc Started Readily
9	Bead-on-Plate	INCONEL WE 112	.190	Insulation,Glyptal	125+ 150	--	P	--	Difficulty with Insulation
10	Bead-on-Plate	Inco-Weld A	.190	Insulation,Glyptal	140	--	P	--	Difficulty with Insulation
11	Bead-on-Plate	R-142	.190	Insulation,Glyptal	130	--	P	--	Difficulty with Insulation
12	Bead-on-Plate	INCONEL WE 112	.190	Insulation, Permatex	--	--	--	--	Difficulty with Insulation
13	Bead-on-Plate	INCONEL WE 112	.190	Insulation,Glyptal	--	--	--	--	Difficulty with Insulation
14	Bead-on-Plate	INCONEL WE 112	.190	Insulation,Glyptal	160- 180	--	--	--	Difficulty with Insulation

TABLE IV (CONTINUED)

New Automatic Rig with Insulated Underwater Electrode Holder

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
A	Bead-on-Plate	INCONEL WE 112	.190	Fresh Water	130	--	--	--	Ran Completely
B	Bead-on-Plate	INCONEL WE 112	.190	Fresh Water	130	--	--	--	Did Not Run Smoothly
C	Bead-on-Plate	Inco-Weld A	.190	Fresh Water	130	--	--	--	Difficult to Start Then Ran Well
D	Bead-on-Plate	E6013	.196	Fresh Water	170	--	P	--	Ran Well But Whipped, Lumpy
E	Bead-on-Plate	E6013	.196	5 oz Counter-weight	170	--	--	--	Good Cup, Still Lumpy
F	Bead-on-Plate	E6013	.196	11-1/2 oz Counter-weight	170	--	--	--	Very Steady, Good Cup
				3-1/2% NaCl Solution, Automatic - 8 ipm Unless Otherwise Indicated					
15	Bead-on-Plate	R-142	.190	11 oz Counter-weight	130	34	G	.0003	1 Fine Pore-Bead Appearance, Best of Series
16	Bead-on-Plate	INCONEL WE 182	.190	11 oz Counter-weight	130	24	P	--	--
17	Bead-on-Plate	INCONEL WE 182	.190	5 oz Counter-weight	120	--	P	.0050	Total 8 - 4 Med. & 4 Fine
18	Bead-on-Plate	INCONEL WE 112	.190	5 oz Counter-weight	120	--	VG	.0003	1 Fine Pore at Start - Good Cup
19	Bead-on-Plate	Inco-Weld A	.190	5 oz Counter-weight	140	36	G	.0036	12 Fine Scattered
20	Bead-on-Plate	R-142	.190	5 oz Counter-weight	130	34	F	.0012	4 Fine, 3 at Start; Good Cup
21	Bead-on-Plate	R-142	.190	No Counterweight	130	35	F-P	.0012	4 Fine Scattered; Some Difficulty Starting
22	Bead-on-Plate	INCONEL WE 182	.190	No Counterweight	120	--	P	.0042	Total 7 - 3 Fine at Start 3 Med. & 1 Fine

TABLE IV (CONTINUED)

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
23	Bead-on-Plate	INCONEL WE 112	.190	No Counterweight	125	36	F-P	.0015	5 Fine Pores, Good Cup
24	Bead-on-Plate	Inco-Weld A	.190	No Counterweight	140	34	F	.0012	2 at Start - 1 Large, 1 Fine
25	Bead-on-Plate	INCONEL WE 112	.190	11 oz Counter-weight	130+ 145	36	F	.0046	Total 11 - 3 Med. & 8 Fine Very Good Cup
26	Bead-on-Plate	Inco-Weld A	.190	11 oz Counter-weight	140	32	G	.0009	3 Fine - 2 at Start; Coating Breaks off Easily
27	Bead-on-Plate	INCONEL WE 182	.190	11 oz Counter-weight	130	--	P	.0027	Total 9 Fine - 3 at Start, Ran Well
28	Bead-on-Plate	R-142	.190	11 oz Counter-weight	130	36	F-G	.0003	1 Small Pore
29	Bead-on-Plate	INCONEL WE 112	.190	11 oz Counter-weight; 10 ipm	130	39	F	.0018	Total 6 - All Fine
30	Bead-on-Plate	INCONEL WE 182	.190	11 oz.Counter-weight; 10 ipm	130	36	G	.0021	Total 7 - All Fine, 4 Near Start, 2 Near End
31	Bead-on-Plate	Inco-Weld A	.190	11 oz Counter-weight; 10 ipm	140	36	P	--	Total 14 Pores - Equipment Difficulty
32	Bead-on-Plate	R-142	.190	11 oz Counter-weight; 6 ipm	130	34	VP	.0075	Total 16 - 6 Med. & 10 Fine; Equipment Difficulty
33	Bead-on-Plate	INCONEL WE 112	.190	11 oz Counter-weight; 6 ipm	130	36	G	0	Clear - Good Cup
34	Bead-on-Plate	INCONEL WE 182	.190	11 oz Counter-weight; 6 ipm	120	36	P	.0053	Total 6 - 1 Med. & 5 Fine
35	Bead-on-Plate	Inco-Weld A	.190	11 oz Counter-weight; 6 ipm	140	32	VG	.0015	Total 5 - Fine
				Manual With Insulated Underwater Electrode - Salt Water					
36	Bead-on-Plate	R-142	.190	--	130	--	P	--	Ran Too Fast
37	Bead-on-Plate	R-142	.190	--	130	--	F	--	Good Cup

TABLE IV (CONTINUED)

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
38	Bead-on-Plate	R-142	.190	--	130	--	P	--	Poor Visibility
39	Bead-on-Plate	INCONEL WE 112	.190	--	--	--	F-G	--	Ran Well, Good Cup
40	Bead-on-Plate	INCONEL WE 182	.190	--	130	36	F	--	Ran Well, Good Cup
41	Bead-on Plate	Inco-Weld A	.190	--	140	32	G	--	Once Started Ran Well,Flux Softens Quickly
Slightly Modified Equipment - 3-1/2% NaCl - 8 ipm - DCSP									
43	Bead-on-Plate	Modified Inco-Weld A	.190	Flux	130	--	F-P	--	Porous Waterproofing
43A	Bead-on-Plate	Modified Inco-Weld A	.190	Flux	130	--	F-P	--	Porous Waterproofing Difficulty with Equipment
44	Bead-on-Plate	Mod. R-142	.190	Flux - 18% $MnCO_3$	130	--	VP	--	Porous Waterproofing; Difficulty with Equipment
45	Bead-on-Plate	R-142	.190	--	130	34	G	0	Clear - Ran Well
46	Bead-on-Plate	Same as 43	.190	Flux	135	--	F-P	.0067	Total 12 - 7 Med. & 5 Fine Rewaterproofed
47	Bead-on-Plate	R-142	.190	--	130	--	F	.0023	Total 3 - Med.; Equipment Difficulty
48	Bead-on Plate	R-142	.190	--	130	--	F	0	Clear
49	Bead-on-Plate	R-142A	.190	Flux - 12% MnO_2	130	--	G	.0003	1 Fine Pore; Ran Well
50	Bead-on Plate	Mod. R-142(b)	.190	Flux - 8% MnO_2	130	--	P	0	Clear; Ran Well for About 1/4 Electrode
51	Bead-on-Plate	Mod. R-142	.190	Flux - 22% $MnCO_3$, No Cb-Core Wire	130	--	VP	--	Severe Porosity
52	Bead-on-Plate	Mod. R-142	.190	Flux - 22% $MnCO_3$, No Cb-Core Wire	130	--	VP	--	Severe Porosity
53	Bead-on-Plate	Same as 52	.190	Flux - 22% $MnCO_3$, No Cb-Core Wire	130	--	VP	--	Severe Porosity

TABLE IV (CONTINUED)

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
54	Bead-on-Plate	Mod. R-142	.190	Flux - 18%$MnCO_3$	130	--	G	.0036	Total 9 - 2 Med. & 4 Fine at Start; 3 Fine Scattered
55	Bead-on-Plate	Mod. R-142	.190	Flux - 22%$MnCO_3$ No Cb, Core, Binder	130	33	VP	--	Severe Porosity
56	Bead-on-Plate	Same as 55	.190	Flux - 22%$MnCO_3$ No Cb, Core, Binder	135	32	VP	--	Severe Porosity - Ran Well
57	Bead-on-Plate	INCONEL WE 112	.220	Coating Dia., Current	130	--	VP	--	--
58	Bead-on-Plate	INCONEL WE 112	.220	Coating Dia., Current	150	48	P	0	Clear
59	Bead-on-Plate	R-142(a)	.220	Coating Dia., Current	155	44	VG	.0123	Total 8 - 4 Med. & 2 Fine at Start, 1 Large & 1 Med. at End
60	Bead-on-Plate	R-142(a)	.220	Coating Dia., Current	--	--	--	--	Apparatus Failure
61	Bead-on-Plate	R-142A	.220	Coating Dia., Current	150	44	VG	.0003	Total - 1 Fine Pore
62	Bead-on-Plate	R-142A	.220	Coating Dia., Current	135	40	G	0	Clear
63	Bead-on-Plate	R-142(a)	.220	Coating Dia., Current	135	40	G	.0079	Total - 1 Large Near Start
64	Bead-on-Plate	INCONEL WE 112	.250	Coating Dia., Current	140→160	--	VP	.0012	Total 4 - Fine Scattered
65	Bead-on-Plate	INCONEL WE 112	.250	Coating Dia., Current	160	--	P	.0015	Total 5 - Fine Scattered
66	Bead-on-Plate	R-142(a)	.250	Coating Dia., Current	140	40	F	0	Clear
67	Bead-on-Plate	R-142(a)	.250	Coating Dia., Current	160	50	P-F	0	Clear, Apparatus Difficulty
68	Bead-on-Plate	R-142A	.250	Coating Dia., Current	150	--	P	0	Clear
69	Bead-on-Plate	R-142A	.250	Coating Dia., Current	160	50	F	.0158	Total - 2 Large Near Start
70	Bead-on-Plate	R-142	.220	Coating Dia., Current	150	44	VG	.0079	Total - 1 Large Near Start

TABLE IV (CONTINUED)

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
71	Bead-on-Plate	R-142	.220	Fresh Water, Current	150	46	F	.0007	Total - 1 Med. Near Start
72	Bead-on-Plate	R-142	.220	Fresh Water, Current	135	--	G	.0007	Total - 1 Med. Near Start
73	Bead-on-Plate	R-142A	.220	Fresh Water, Current	130→160	44	P	0	Clear
74	Bead-on Plate	R-142A	.220	Fresh Water, Current	150	46	G	.0026	Total - 4 at Start, 3 Med., 1 Fine
75	Bead-on-Plate	INCONEL WE 112	.190	Fresh Water, Current	125	36	G	0	Clear, Poor Slag Removal
76	Bead-on-Plate	INCONEL WE 112	.190	Fresh Water, Current	105	34	G	0	Clear, Poor Slag Removal
77	Bead-on-Plate	E6013	.196	Fresh Water, Current	160	28	F	.0158	Total - 2 Large Near Start
78	Multiple Bead	INCONEL WE 112	.190	Coating Dia., Groove	130	36	G	.0015	Total 5 - 2 at Restrike, 3 at End, All Fine
79	Multiple Bead	E6013	.196	Groove	165	28	G	.0015	Total 5 - 5 Fine Near Start
80	Multiple Bead	R-142(a)	.220	Groove	150	44	F-G	.0041	Total 9 - 3 Med. & 2 Fine at Start & 4 Fine Scattered, Difficulty With Apparatus
81	Multiple Bead	R-142A	.220	Groove	150	46	F-G	.0081	Total 18 - 2 Med. & 12 Fine at Start, 4 Med.
82	Bead-on Plate	R-142	.190	Current	120	34	F-G	0	Clear
83	Bead-on-Plate	R-142	.190	Current	170	40	G	.0069	Total 17 - 3 at Start, 4 Med. - 13 Fine
84	Bead-on-Plate	R-142A	.190	--	--	--	--	--	Could Not Start - Poor Waterproofing
85	Bead-on-Plate	R-142A	.190	Current	165	--	G	.0069	Total 17 - 2 Med. at Start 2 Med at End, Rest are Fine
86	Multiple Bead	R-142	.190	Groove	150	39	G	.0028	Total 8 - 1 Med., 7 Fine - All Near Start & End of Beads

TABLE IV (CONTINUED)

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
87	Bead-on-Plate	R-142A	.190	Coating Dia., Current	165	41	VG	.0066	Total 13 - 1 Med. at Start 5 Med. at End, 7 Fine Scattered
88	Bead-on-Plate	R-142A	.190	Coating Dia., Current	130	38	G	.0024	Total 5 - 2 Med. at Start, 3 Fine at End
89	Bead-on-Plate	Mod. Inco-Weld A	.190	Flux	110	--	F	0	Clear, Slag Removal Needs Improvement
90	Bead-on-Plate	Mod. Inco-Weld A	.190	Flux, Current	135	38	F	.0027	Total 9 - 1 Fine at Start, Others are Fine Scattered
91	Multiple Bead	R-142	.190	Groove	155	40	VG	.0111	Total 22 - 10 Med.,12 Fine 11 in Last 1-1/2" of Weld
92	Multiple Bead	R-142A	.190	Groove, Current	150	38	G	.0152	Total 34 - 11 Med.,23 Fine
93	Multiple Bead	R-142	.220	Groove, Current	140	43	VG	0	Clear
94	Multiple Bead	R-142A	.220	Coating Dia., Current	140	43	G	.0033	Total 11 - Fine
95	Multiple Bead	PD Mod. Inco-Weld A	.190	Flux	150	38	F	.0308	Total 40 - 2 Large,8 Med., 30 Fine
96	Multiple Bead	INCONEL WE 112	.190	Groove	130	36	F	.0017	Total 4 - 3 Near Start, 1 at Interruption, 1 Med. & 3 Fine
97	Multiple Bead	E6013	.196	Groove	160	27	G	.0079	Total 1 Large - Near Start
98	Multiple Bead	INCONEL WE 112	.190	--	--	--	--	--	Equipment Difficulty
99	Multiple Bead	R-142	.190	--	--	--	--	--	Equipment Difficulty
100	Multiple Bead	R-142	.220	Groove Coating Dia.	140	42	VG	.0015	Total 5 - 5 Fine in First 1/2 Inch
101	Multiple Bead	R-142A	.190	Groove	140	42	G	.0015	Total 5 - 2 Fine at Start, 3 About 1-1/2 Inches From Start - 2 Med. & 1 Fine
102	Multiple Bead	INCONEL WE 112	.190	Groove	140	42	F	.0021	Total 7 - 3 Fine at Start, 4 at End, Slag Hard to Remove

TABLE IV (CONTINUED)

Weld No.	Type Weld	Electrode	Coating Dia. (in)	Variable(s)	Avg. Amp.	Avg. Volts	Bead Appearance	Porosity Cross Sectional Area (sq.in)	Porosity/Remarks
103	Multiple Bead	R-142	.190	Groove	140	36	G	.0022	Total 6 - 4 Fine Near Start, 2 Scattered, 1 Med., 1 Fine
104	Multiple Bead	E6013	.196	Groove	160	27	G	.0007	Total 1 - Fine Near End, Undercut
105	Multiple Bead	R-142	.190	Groove, Restrikes	135	44	F-G	.0124	Total 10 - 4 Med. & 1 Large, 5 Fine Near Start, Equipment Difficulty, Defect

(a)Made at PDMRL.
(b)12%MnO_2.

TABLE V

EFFECT OF DOWNWARD FORCE ON ELECTRODE ON BEAD APPEARANCE AND POROSITY

Electrode	Weld	Weight on Electrode	Bead Appearance	Porosity
R-142	15	1	VG*	.0003
	20	1-1/2	F	.0012
	21	2	F	.0012
INCONEL Welding Electrode 182	27	1	P	.0027
	17	1-1/2	P	.0050
	22	2	P	.0042
INCONEL Welding Electrode 112	25	1	F	.0046
	18	1-1/2	VG	.0003
	23	2	F-P	.0015
Inco-Weld A	26	1	G	.0009
	19	1-1/2	G	.0036
	24	2	F	.0012

*Best of series.
All welds made at 8 inches per minute.

TABLE VI

EFFECT OF TRAVEL SPEED ON BEAD APPEARANCE AND POROSITY

Electrode	Weld No.	Travel Speed (ipm)	Bead Appearance	Porosity Total Cross Sectional Area (sq.in)
R-142	32	6	P	.0075
	15	8	VG	.0003
	28	10	F-G*	.0003
INCONEL Welding Electrode 182	34	6	P	.0053
	27	8	P	.0027
	30	10	G	.0021
INCONEL Welding Electrode 112	33	6	G	0
	25	8	F	.0046
	29	10	F	.0018
Inco-Weld A	35	6	VG	.0015
	26	8	G	.0009
	31	10	P	--

*Narrow bead.
All welds made with 1 pound downward force on electrode.

TABLE VII

EFFECTS OF FLUX VARIATIONS ON BEAD APPEARANCE AND POROSITY

Weld No.	Electrode Flux	Electrode Core	Major Flux Variables	Bead Appearance	Porosity, Cross Sectional Area (sq.in)
45	1	A	Standard (18%MnO_2)(a)	Good	0
47	2	B	Standard(b)	Fair(c)	.0023
48	2	B	Standard	Fair	0
49	3	B	12%MnO_2	Good	.0003
50	4	B	8%MnO_2	Poor	0
54	6	C	$MnCO_3$ for MnO_2	Good	.0036
51	5	D	No FeCb, Increased $MnCO_3$, and Other	Very Poor	Severe
52	5	D	Ingredients, No MnO_2	Very Poor	Severe
53	5	C	Same as 51 & 52 Except for Core Wire	Very Poor	Severe
55	7	E	Same as 51 & 52 but K_2SiO_3	Very Poor	Severe
56	7	E	Substituted for Na_2SiO_3, Different Core Wire	Very Poor	Severe

(a) Produced commercially.
(b) Produced at PDMRL.
(c) Acceptable.

TABLE VIII

EFFECT OF CURRENT ON BEAD APPEARANCE AND POROSITY

Type Electrode	Weld No.	Type Weld	Coating Dia. (in)	Avg. Amperage	Bead Appearance	Porosity-Cross Sectional Area (sq.in) Total	Porosity-Cross Sectional Area (sq.in) Per Electrode
R-142	82	Bead-on-Plate	0.190	120	F-G	0	0
	15	Bead-on-Plate	0.190	130	VG	.0003	.0003
	45	Bead-on-Plate	0.190	130	G	0	0
	83	Bead-on-Plate	0.190	170	G	.0069	.0069
	86	Multibead, Shallow Groove	0.190	150	G	.0028	.0009
	91	Multibead, Shallow Groove	0.190	155	VG	.0111	.0037
	63	Bead-on-Plate	0.220	135	G	.0079	.0079
	70	Bead-on-Plate	0.220	150	VG	.0079	.0079
	59	Bead-on-Plate	0.220	155	VG	.0123	.0123
R-142A	49	Bead-on-Plate	0.190	130	G	.0003	.0003
	88	Bead-on-Plate	0.190	130	G	.0024	.0024
	85	Bead-on-Plate	0.190	165	G	.0066	.0066
	87	Bead-on-Plate	0.190	165	VG	.0069	.0069
	62	Bead-on-Plate	0.220	135	G	0	0
	61	Bead-on-Plate	0.220	150	VG	.0003	.0003
	68	Bead-on-Plate	0.250	150	P	0	0
	69	Bead-on-Plate	0.250	160	F	.0158	.0158

TABLE IX

EFFECT OF COATING THICKNESS ON BEAD APPEARANCE AND POROSITY

Type Electrode	Coating Dia. (in)	Type Weld	Weld No.	Amperes	Voltage	Bead Appearance	Porosity-Cross Sectional Area (sq.in) Total	Per Electrode
R-142	0.190	Bead-on-Plate	82	120	34	F-G	0	0
		Bead-on-Plate	15	130	34	VG	.0003	.0003
		Bead-on-Plate	45	130	34	G	0	0
	0.220	Bead-on-Plate	63	135	40	G	.0079	.0079
		Bead-on-Plate	70	150	44	VG	.0079	.0079
	0.250	Bead-on-Plate	66	140	40	F	0	0
	0.190	Multipass, Shallow Groove	86	150	39	G	.0028	.0009
	0.220	Multipass, Shallow Groove	93	140	43	VG	0	0
	0.190	Multipass, Deeper Groove	103	140	36	G	.0022	.0007
	0.220	Multipass, Deeper Groove	100	140	42	VG	.0015	.0005
INCONEL Welding Electrode 112	0.190	Bead-on-Plate	25	140	36	F	.0046	.0046
	0.220	Bead-on-Plate	57	130	--	VP	--	--
		Bead-on-Plate	58	150	48	P	0	0
	0.250	Bead-on-Plate	64	150	--	VP	.0012	.0012
		Bead-on-Plate	65	160	--	P	.0015	.0015

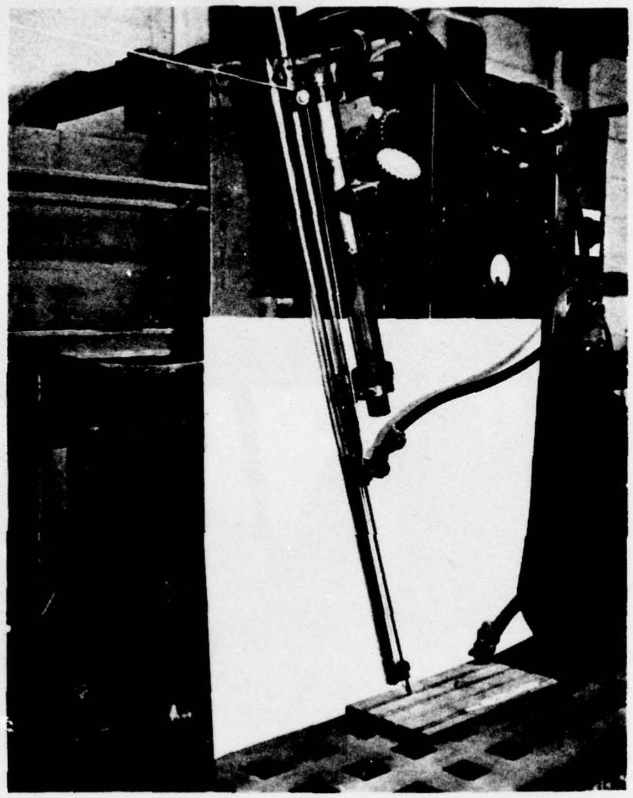

FIGURE 1

FIRST AUTOMATIC WELDING FIXTURE

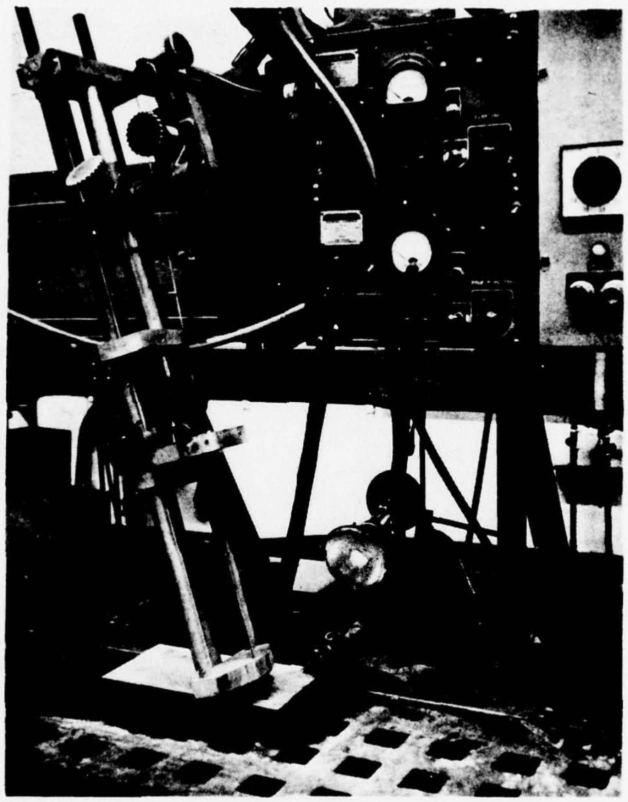

FIGURE 2

SECOND AUTOMATIC WELDING FIXTURE

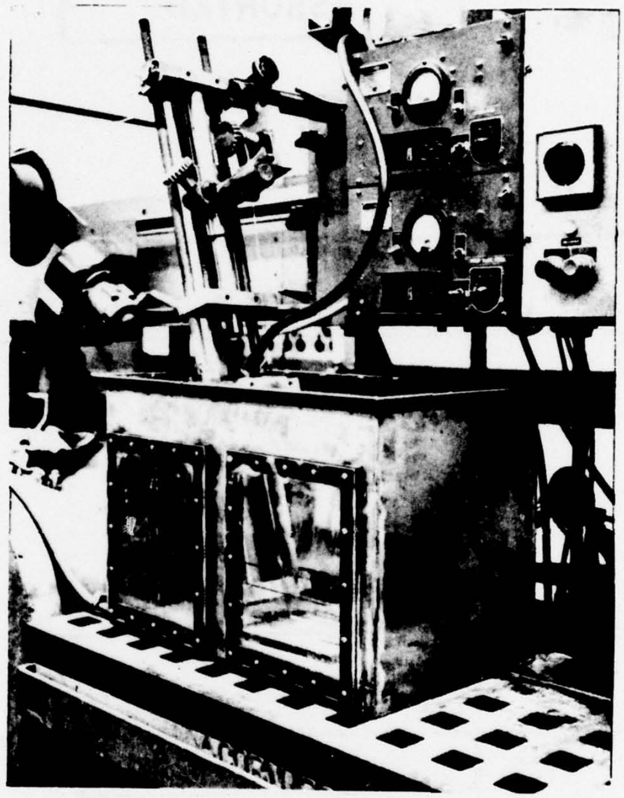

FIGURE 3

FIXTURE IN WATER TANK

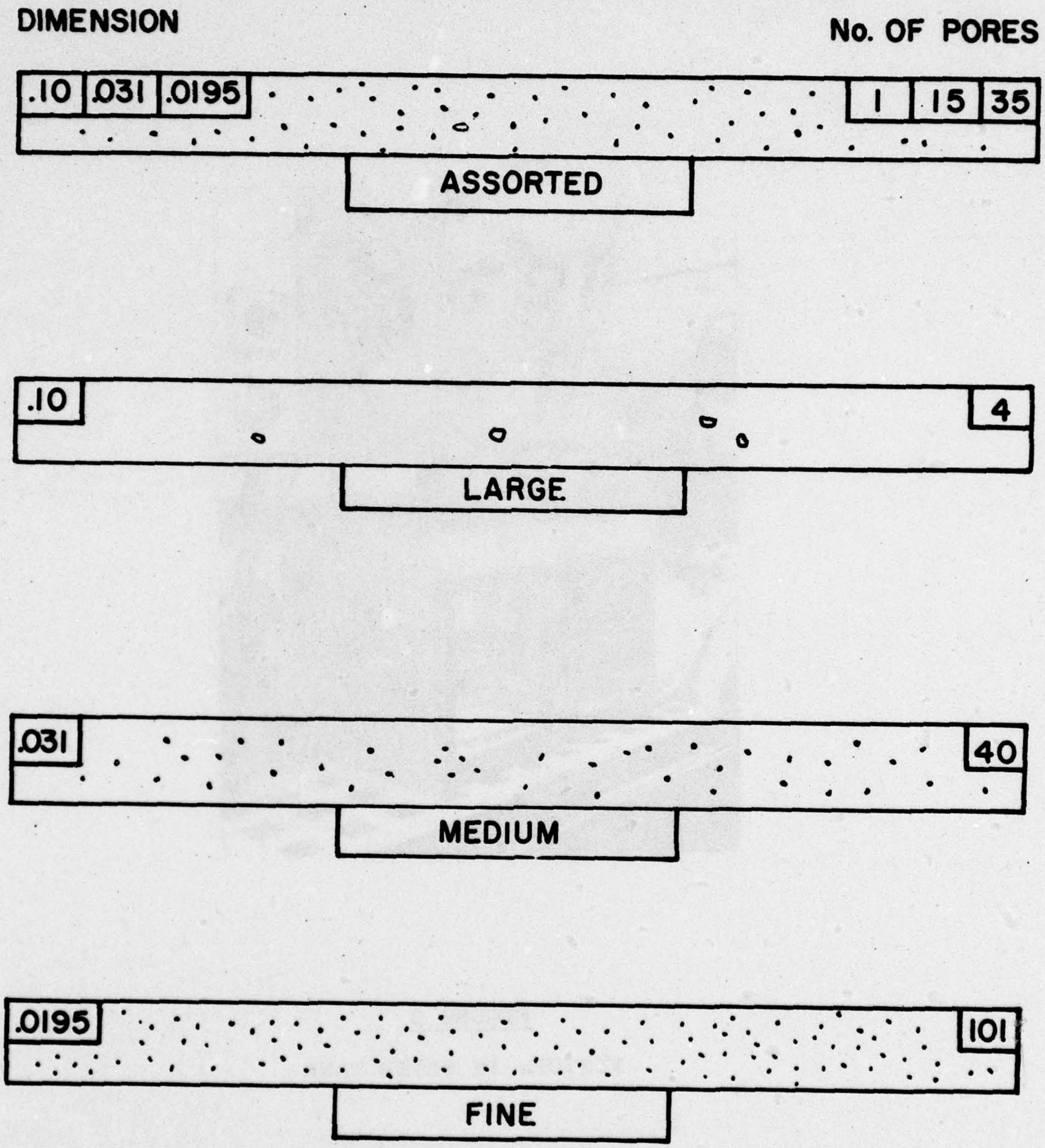

FIGURE 4 - POROSITY REFERENCE CHART.

FIGURE 5

STRAIGHT POLARITY VS. REVERSE POLARITY ·(FRESH WATER)

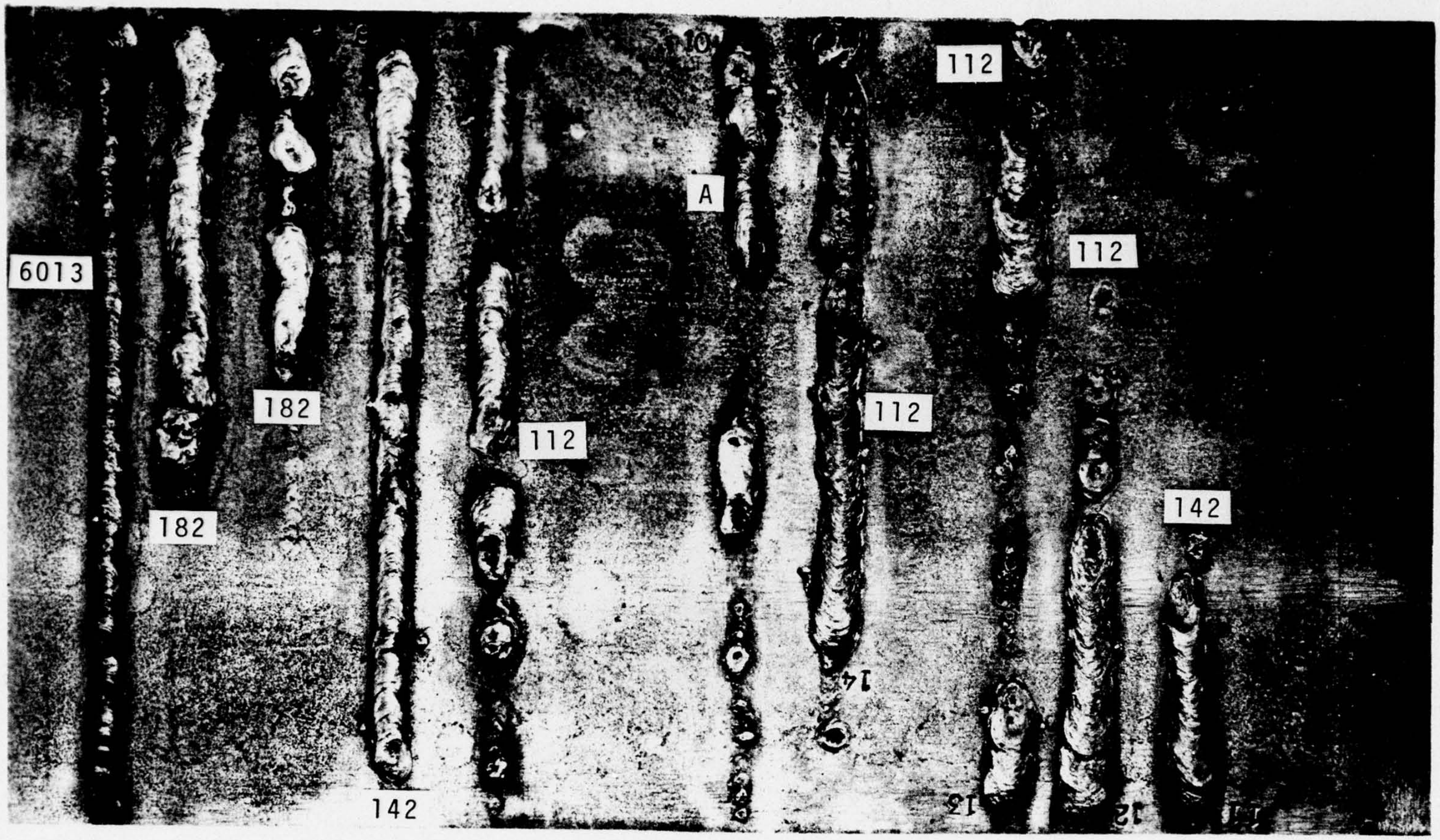

FIGURE 6

BEAD ON PLATE MADE WITH FIRST AUTOMATIC FIXTURE

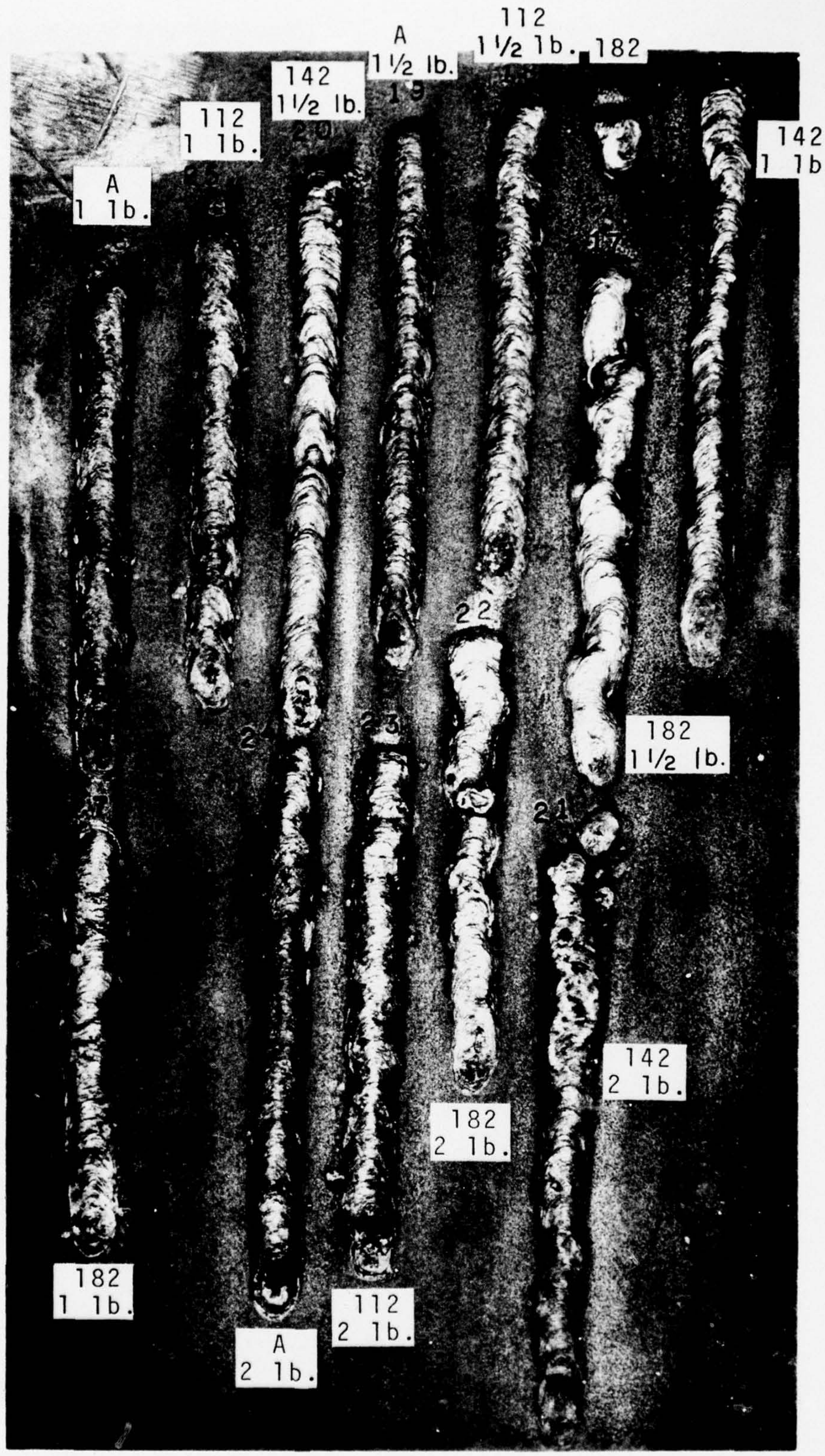

FIGURE 7

EFFECT OF CHANGE IN "DOWNWARD FORCE"
ON BEAD APPEARANCE

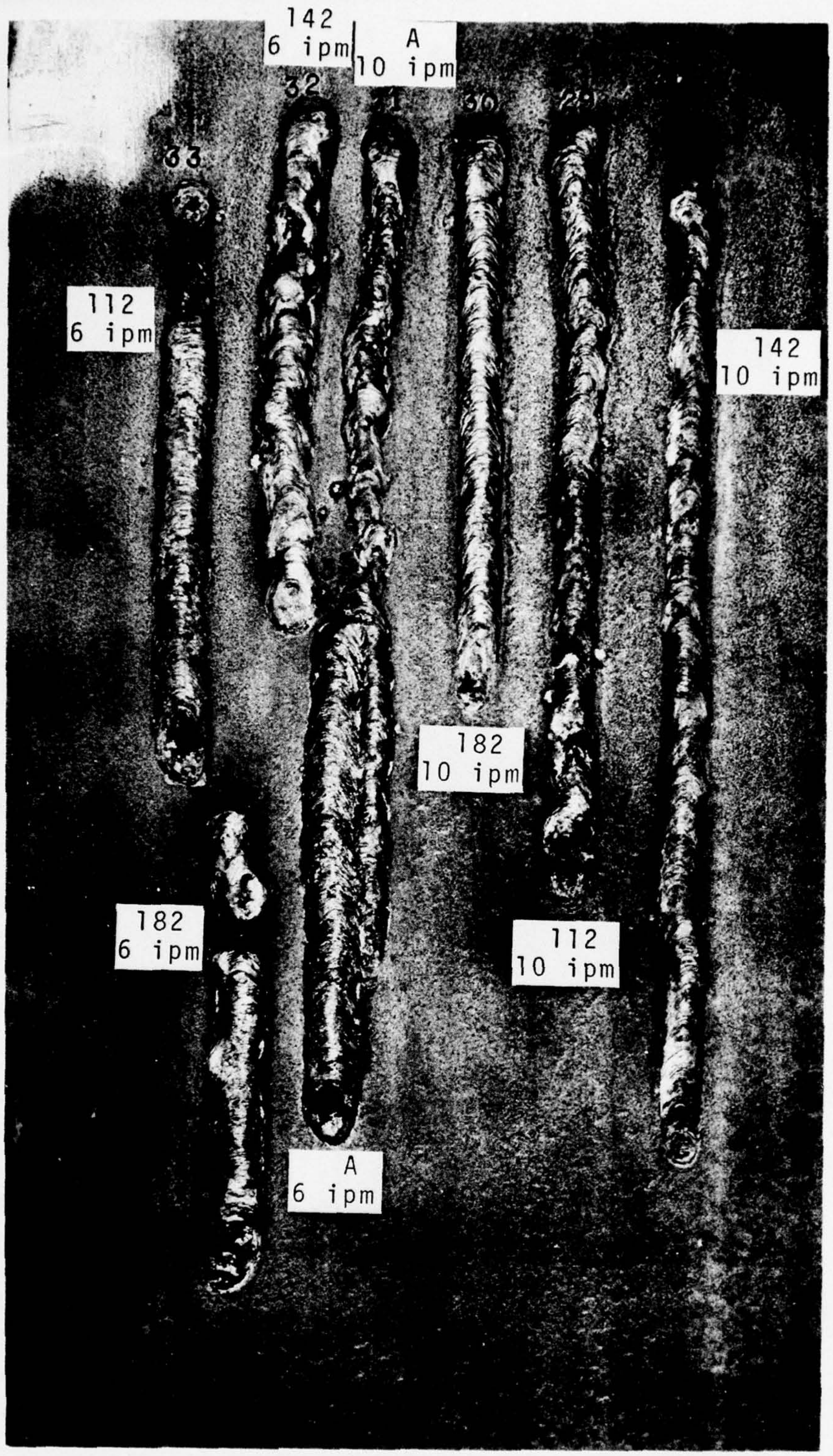

FIGURE 8

EFFECT OF CHANGE IN TRAVEL SPEED ON
BEAD APPEARANCE

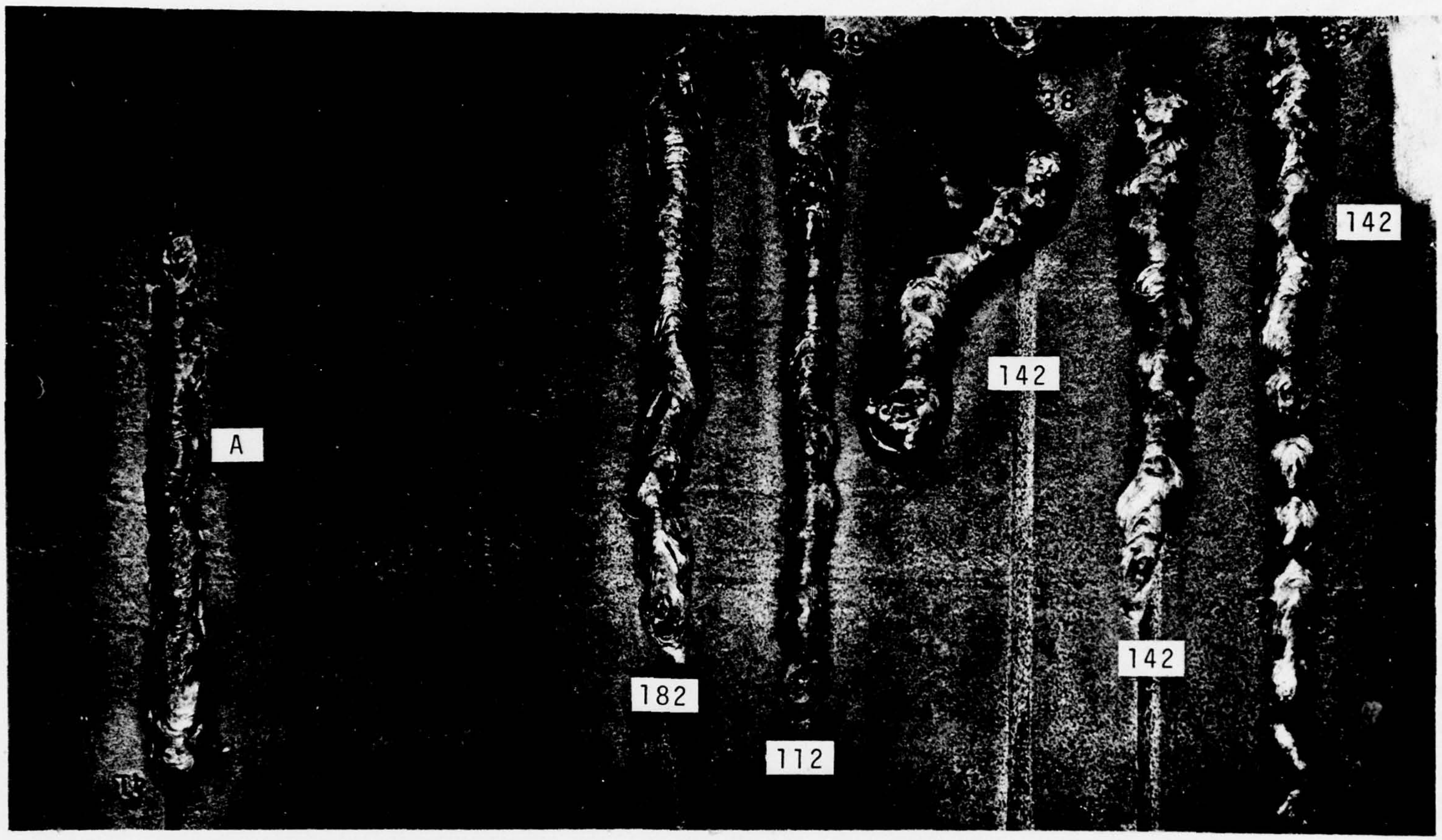

FIGURE 9

MANUAL WELDS MADE WITH INSULATED UNDERWATER ELECTRODE HOLDER

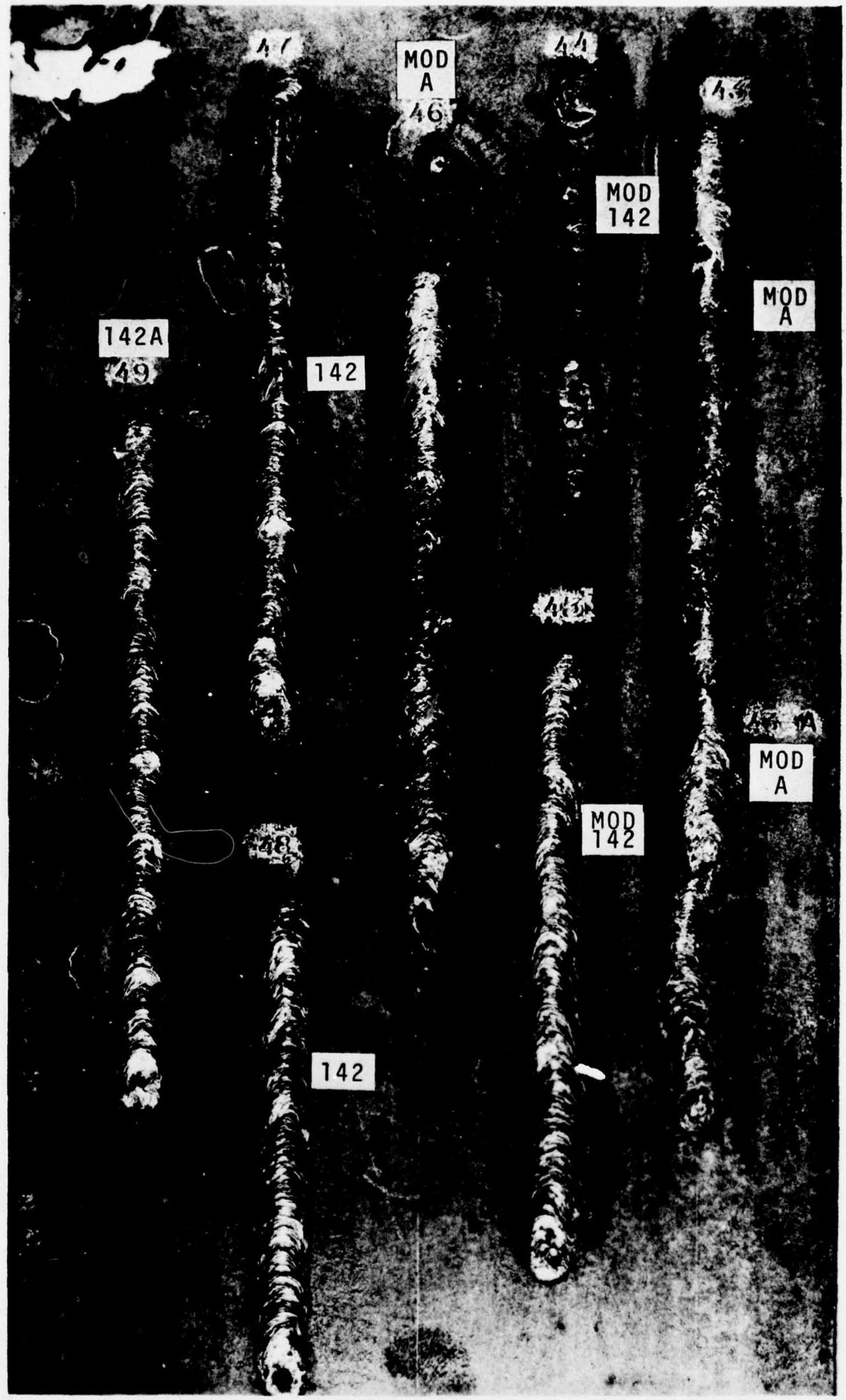

FIGURE 10

EFFECT OF FLUX MODIFICATIONS

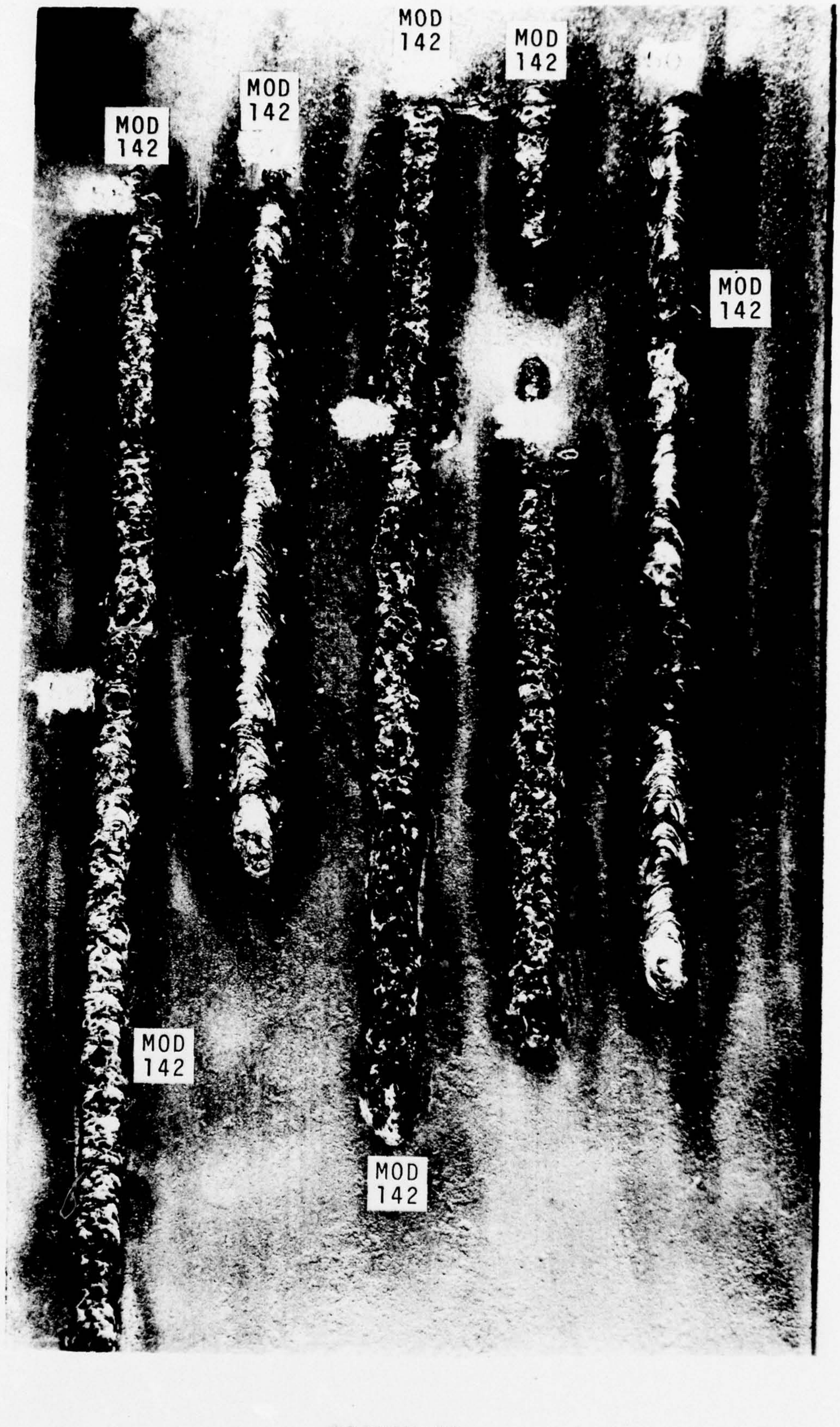

FIGURE 11

ADDITIONAL WELDS MADE WITH MODIFIED FLUXES

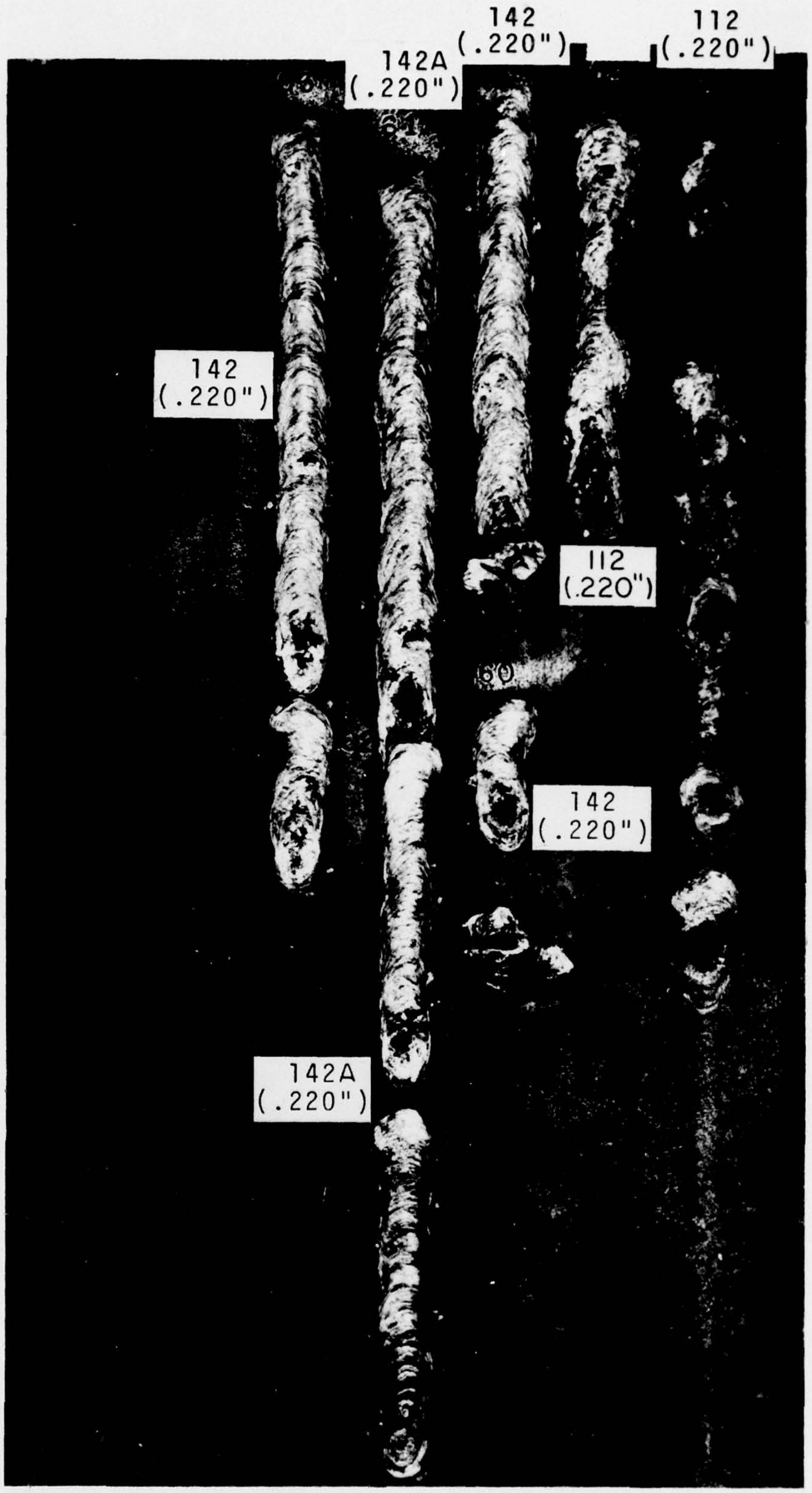

FIGURE 12

WELDS MADE WITH DIFFERENT COATING THICKNESSES AND CURRENT

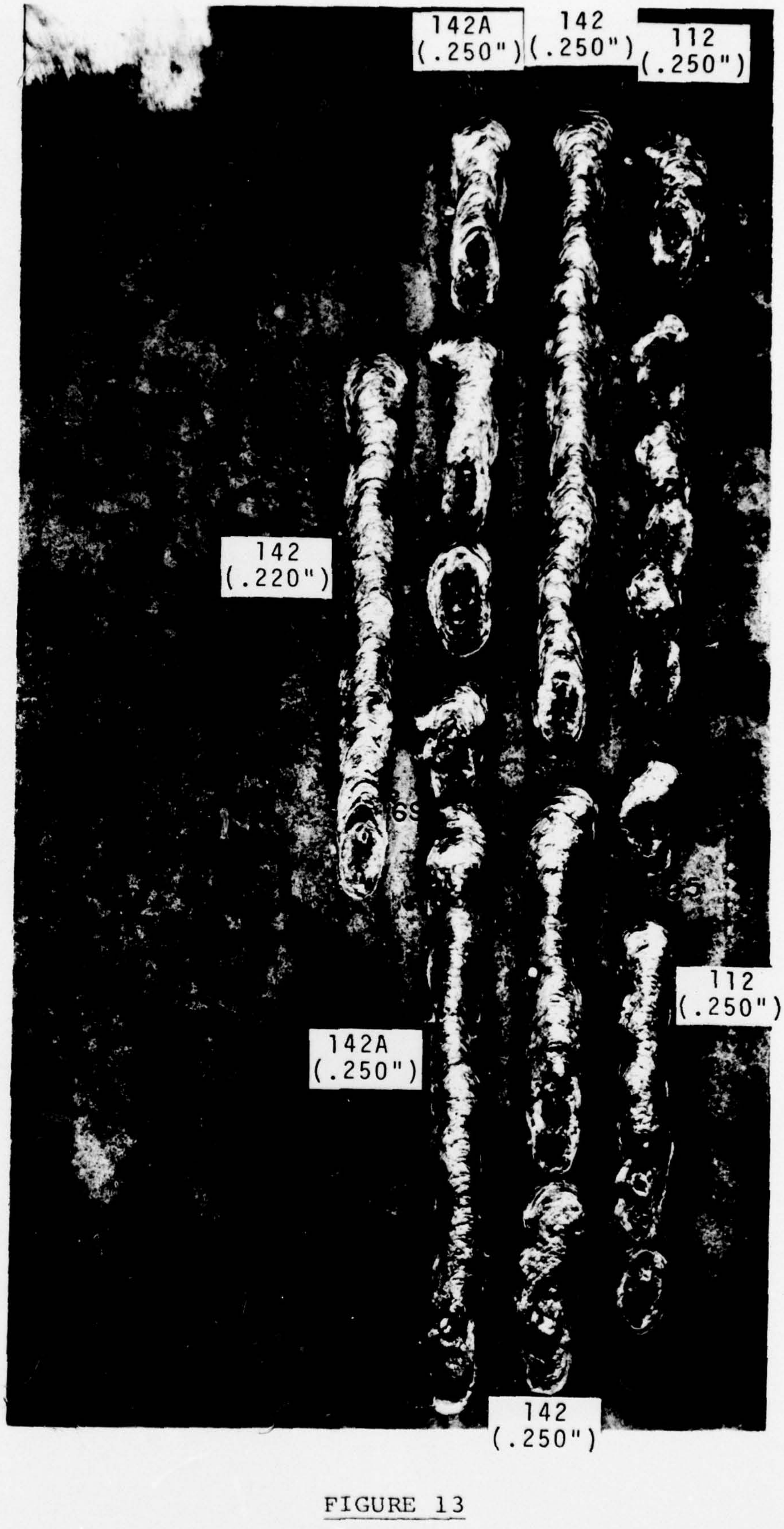

FIGURE 13

ADDITIONAL WELDS MADE WITH DIFFERENT
COATING THICKNESSES AND CURRENT

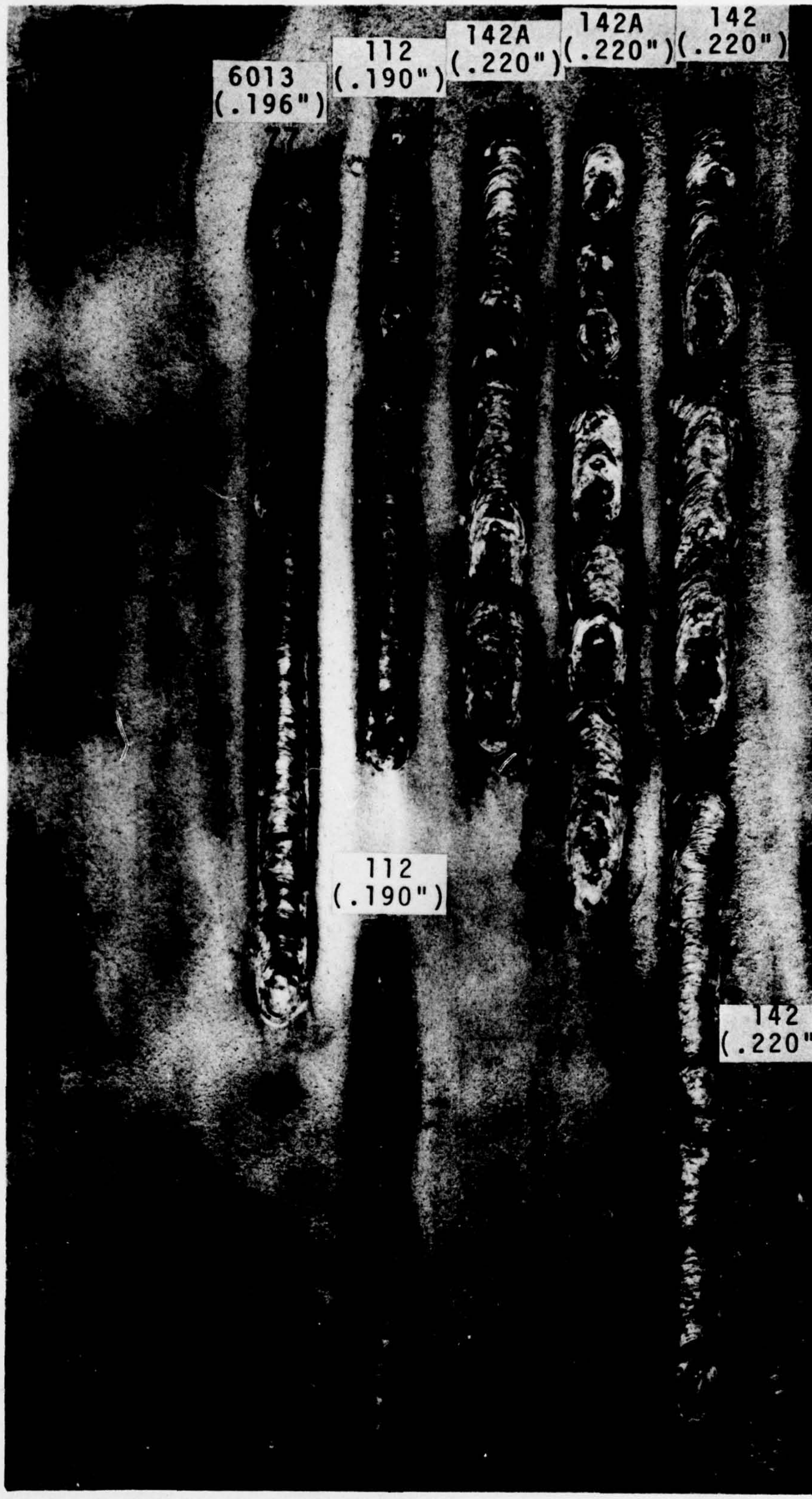

FIGURE 14

WELDS MADE AUTOMATICALLY IN FRESH WATER

FIGURE 15

FIRST MULTIPASS WELDS MADE IN A SHALLOW GROOVE

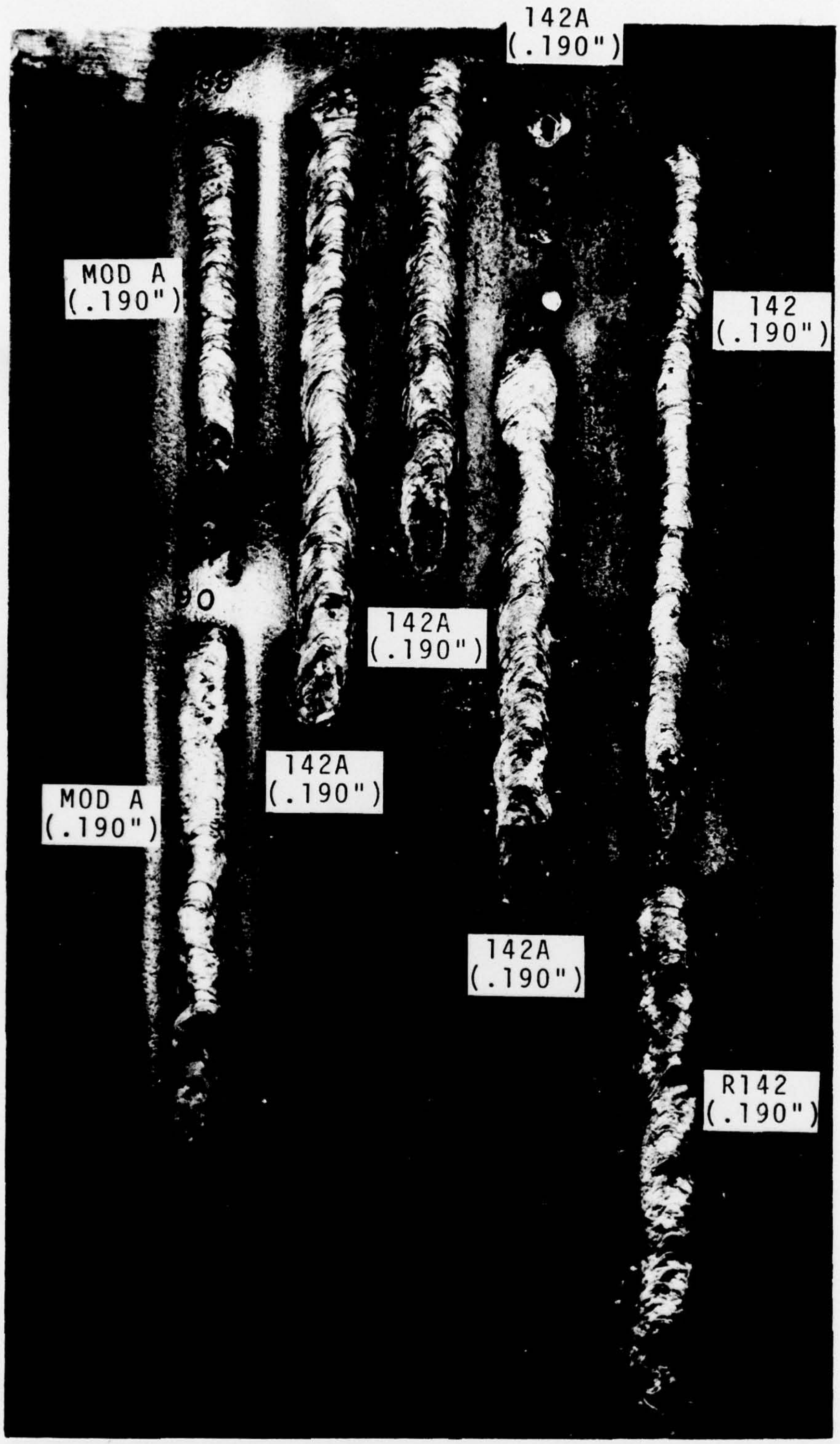

FIGURE 16

SOME OF THE WELDS USED TO ESTABLISH
THE EFFECT OF CURRENT

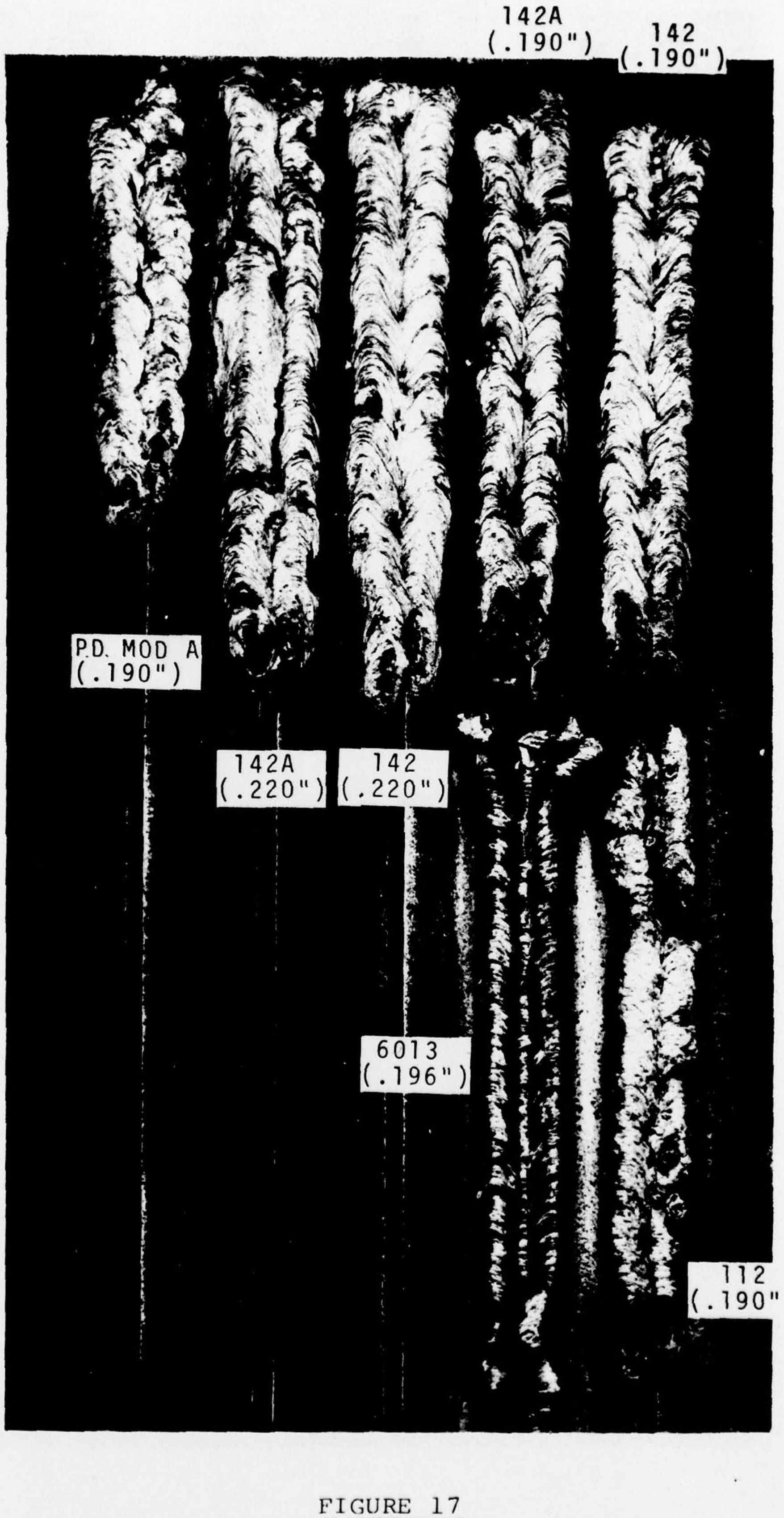

FIGURE 17

ADDITIONAL MULTIPASS WELDS MADE IN
THE SHALLOW GROOVE

FIGURE 18

MULTIPASS WELDS IN THE DEEPER GROOVE

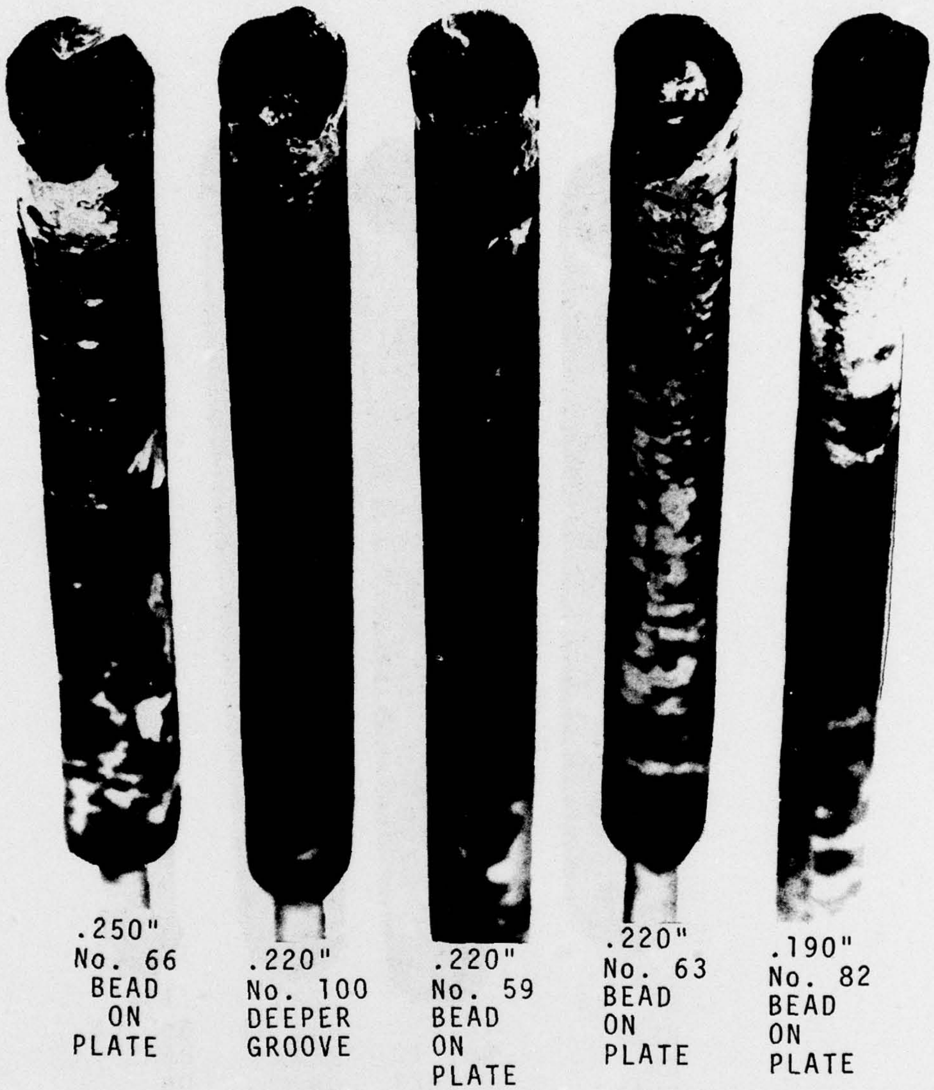

FIGURE 19

COATING THICKNESS VS. CUP DEPTH (R142)

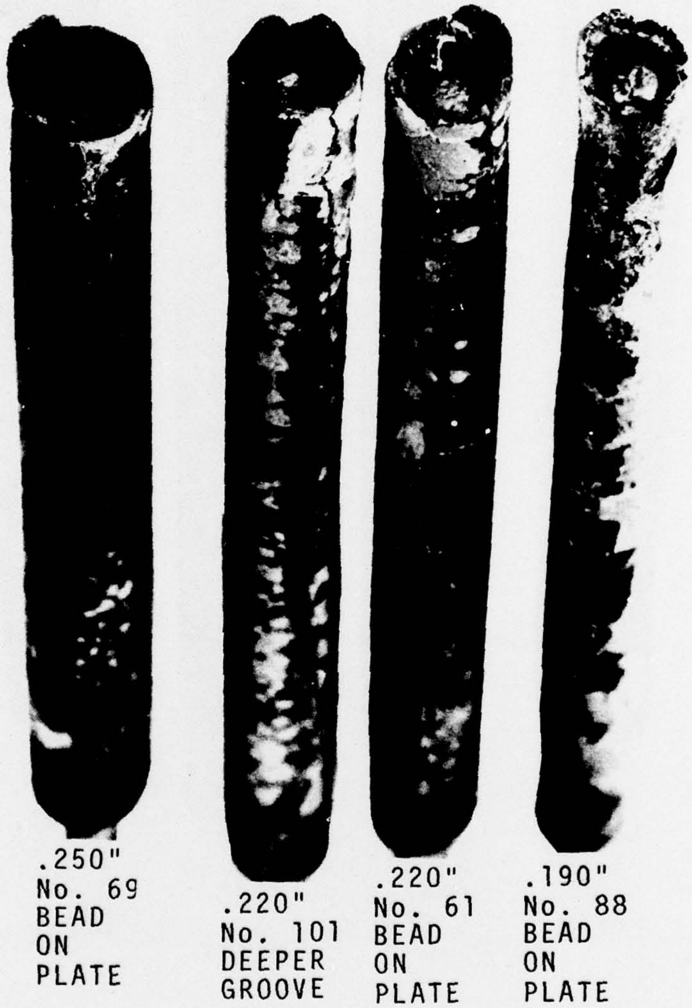

FIGURE 20

COATING THICKNESS VS. CUP DEPTH (R142A)

FIGURE 21

CUP DEPTH - E6013 AND INCONEL WELDING ELECTRODE 112
(.250" COATING)

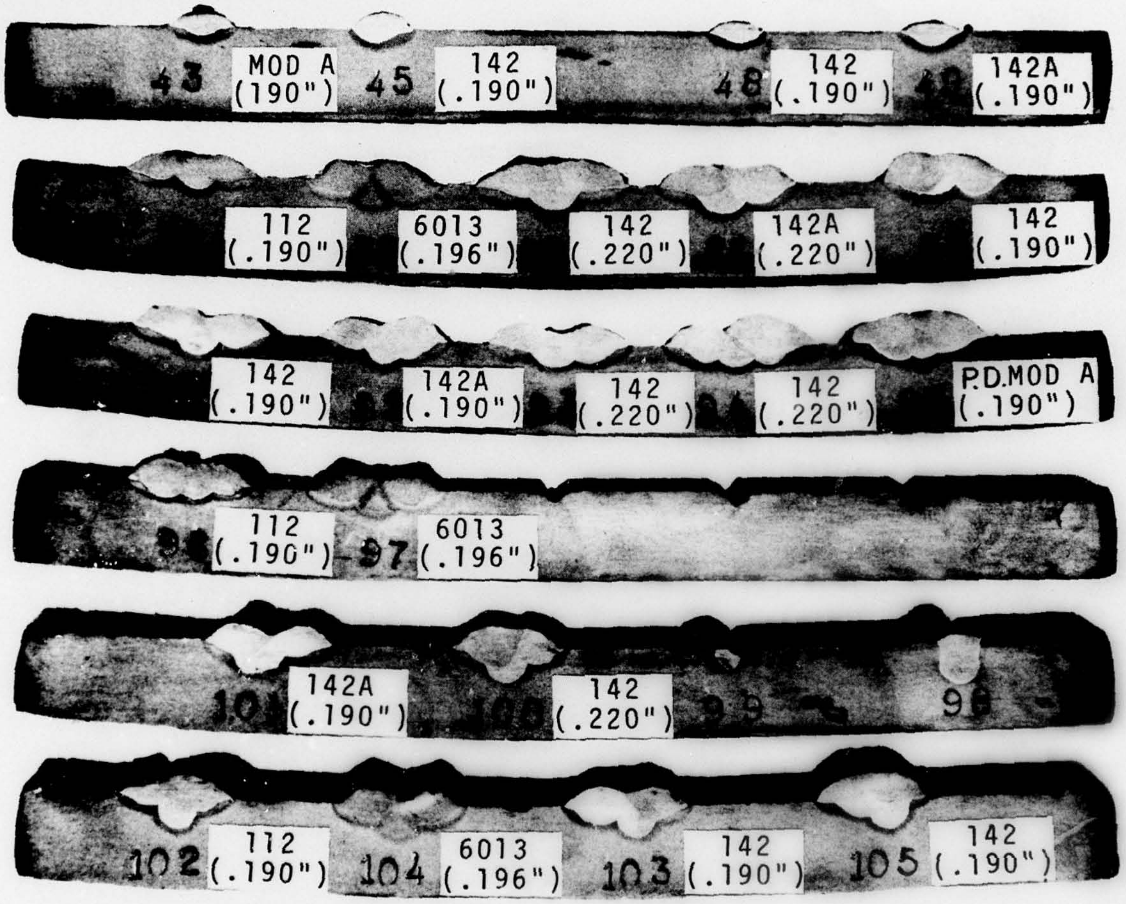

FIGURE 22

CROSS SECTIONS OF VARIOUS WELDS